RODGERS

The Design and Construction Of a Recording Accelerometer

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THE DESIGN AND CONSTRUCTION OF A RECORDING ACCELEROMETER

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

ROBERT BEAM RODGERS

ENTITLED THE DESIGN AND CONSTRUCTION OF A RECORDING ACCELEROMETER

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Railway Electrical Engineering

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The Design and Construction of an Accelerometer.

INTRODUCTION.

The advent of the electric motor as a competitor of the steam engine in the traction field, has given rise to certain acceleration problems unfamiliar to engineers of a generation ago. At a time when the train mile was a satisfactory unit in which to reckon haulage costs, there was little occasion to bother with acceleration. Now, however, train schedules are constantly being increased and more energy is expended in accelerating than in overcoming frictional and grade resistances.

Hence modern railway practice demands a simple, accurate, and reliable means of measuring acceleration.

HISTORY.

Professor R. B. Owens in the transactions of the Canadian Society of Civil Engineers for 1905, describes a laboratory instrument for measuring acceleration. As shown in Fig. 1. S is the shaft or car axle whose velocity is to be measured. C is a mechanical coupler. A_1 is the armature of a small permanent magnet or constantly excited continuous current dynamo wound so as to have a negligible reaction within the limits of its use. R is a variable non-inductive resistance to limit the current flowing from the armature and A is a zero centre direct current ammeter. T is a transformer with its secondary connected, for purposes of adjustment, through a non-inductive resistance R_1, to a zero centre direct current voltmeter. The reading of the volt-

meter V will then be proportional to the acceleration, positive or negative of the shaft S. The transformer must have a straight line magnetization curve and a large transformation ratio as the secondary induced voltage is necessarily small and the voltmeter V must also be sensitive to small currents. The calibration of the ammeter as a speed indicator is effected by driving the armature A at different constant speeds as shown by ammeter reading and taking the revolutions in a given time by means of a revolution counter and stop watch. The calibration of the voltmeter as an accelerometer is best done by driving the armature A by a separately and constantly excited motor having applied to its armature, preferably of small momentum, a voltage varying approximately as a linear function of time. With proper manipulation of apparatus the ammeter readings plotted against time will be a straight line, whose slope will be constant and equal to the acceleration and to the constant reading of the voltmeter.

DESIGN.

The first thing of importance to determine in the design of this instrument was the ratio of transformation and the type of transformer to use. This was found by experiment as shown in Fig.2. A is a stove pipe rheostat connected directly across 110 volt direct current mains. V is a 0 to 20 zero center millivoltmeter, which is connected to the secondary of the transformer. The current flowing thru the primary of the transformer can be varied at will by moving the contactor C to any position along A.

The first transformer tried was constructed similar to an

induction coil. A wood spool 8 inches long and 2 1/2 inches in diameter with a hole in center 1 inch in diameter was wound with 2 layers of number 16 cotton covered copper wire for the primary. On this was wound 500 layers of number 36 cotton covered copper wire for the secondary. The hole in the spool was filled with soft iron wires. When this was connected as shown in diagram, the maximum deflection on the millivoltmeter was 7 millivolts. Even this deflection was obtained only when C was moved almost instantly from 0 to maximum, which is a very much greater change in the current flowing in the primary of the transformer than could ever occur with the dynamo attached to the car axle. The next transformer tried was one with an air core. The spool was 5 inches long and 3 inches in diamter. Number 22 cotton covered copper wire was used for both primary and secondary windings. The ratio of transformation was 10 to 1. The results of this test was 5 millivolts as a maximum. The same spool was used with a ratio of 20 to 1. This gave a deflection of 7 millivolts as a maximum. A flat spool with an air core was tried. The same size wire was used as before and the ratio of transformation was 30 to 1. The dimensions of spool were 1 inch long and 6 inches in diameter. This gave a maximum deflection of 8 millivolts. An iron core transformer with a ratio of 20 to 1 was finally tried, and a deflection across the entire scale was obtained with only a gradual change in the resistance at C.

It was thought that an iron core transformer would show an appreciable lag in the flow of the secondary current, which would introduce sufficient error to prevent its use. This did

not prove to be true when tried, as the needle of the voltmeter, as far as the eye could detect, followed the contact C practically instantaneously.

CONSTRUCTION.

The next problem was to determine a means of making a permanent record of the deflections. Voltmeters and ammeters are often made self-recording by attaching a pen to the pointer and tracing the curve on a sheet of moving paper. But the error introduced by the introduction of the pen on the paper would be so large as to prohibit the use of this type of recording device. The means adopted was a jump spark method, which is shown in Fig. 3. V is the 0-20 Weston millivoltmeter. The scale was removed and a 3/8 inch fibre plate substituted. In this plate a 1/8 inch brass strip D was let into the scale until it was flush with the top of fibre. One quarter inch from this and concentric with the strip were placed 70 strips of copper extending out radially. These were all equally spaced over the entire scale, and were let into a recess, which brought them flush with the top of the fibre. The spaces between each strip was filled with sheet mica. To each strip a number 20 rubber covered copper wire was soldered. To obtain a better method of insulation and to give more room for soldering, the strips were made to extend different distances from the fibre, as shown in Fig. 4. The wires at other end were inserted through holes drilled in a fibre strip G. This piece G was placed directly over a brass sheet C. Between this sheet of brass C and the fibre G, a sheet of paper is kept moving by an electric

motor. The needle or points N of the millivoltmeter V was cut in two about 1 1/2 inches from the indicating end and small piece of broom straw B inserted. This is used merely as an insulator to prevent the high tension current from entering the armature of the millivoltmeter. L is the secondary of an induction coil, one terminal of which connects to the brass strip D and the other to the brass sheet C. P is the primary of the induction coil to which is connected, through the switch S, the 8 volt storage battery E. The path of the secondary or high tension current is to strip D jumping to the needle N, following it to the end, jumping to which ever point the needle is over, from this point through its corresponding wire, through the strip of paper A to the brass sheet C, and return. The curve appear as a series of small holes burned through the paper.

MOUNTING AND TESTING.

The instrument was set up in the Electrical Engineering Test Car of the University of Illinois. Fig. 5 shows the diagramatic sketch of the entire connections for the instrument. K is a 1/2 kilo-watt separately excited direct current dynamo driven from the car axle by a spring steel belt. The field is excited from the 12 volt storage battery and is kept constant by means of the adjustable resistance R. The ammeter A is simply to indicate any change of the current flowing in the filed M. T is the transformer the primary of which is connected directly across the terminals of the dynamo. The secondary of the transformer is connected to the millivoltmeter. The paper roll A is 40 inches long and is

ordinarily driven by a 500 volt direct current motor connected to the trolley circuit. It is also arranged to be driven from the car axle. Records of voltage, current, speed, time, and brake application are recorded on the same sheet. The accelerometer occupying about 8 inches at one end of the roll. All the pens of the instruments as well as the strip of fibre G Fig. 3, are placed in a straight line so that all the records show at the same instant. The rest of the apparatus has already been explained in detail.

DISCUSSION.

The first test of this instrument was made on the Illinois Traction System's lines between Champaign, Ill., and St. Joseph, Ill. The track is practically level and a number of starts and stops were made in order to obtain the maximum acceleration and retardation. A second test was run between Champaign and Urbana.

The acceleration was obtained from the formula:

$$A == 0.733 \frac{V_2^2 - V^2}{S}$$

V_1 and V_2==the speed at the entrance and exit of the section in miles per hour.

S==length of the section in feet.

A==average acceleration over section in miles per hour per second.

A and B figure 6 represent curves reproduced from the chart taken in the car. These are drawn as near as possible to the same scale as the originals. C represents the acceleration curve as calculated from the speed curve by the abov formula.

Figure 7 shows actual curves reproduced from the chart giving the relative positions of the speed, brake pressure, and retardation curves in stopping. At a maximum braking pressure of 70 pounds per square inch a retardation of slightly over 2 miles per hour per second was obtained. None of the accelerating curves showed an acceleration quite this high. About 1.8 being the maximum.

Figure 8 is the calibration curve for this instrument. Figure 9 is a piece cut from the original chart showing the curve as actually taken in the operation of the instrument. In the two tests made with the instrument a total of 24 acceleration and retardation curves were obtained. The irregularities in the acceleration curve were due to the millivoltmeter needle being slightly unbalanced and to the vibrations and swing of the car. The needle being made of aluminum and placed lengthwise of car eliminated all chance for any deflection due to sudden starting and stopping of the car. With the addition of the insulated joint in the needle it was practically impossible to obtain exactly the balance of the needle. Whether the passing of the high tension current through the needle had any influence on its accuracy it was impossible to determine. At high speeds the sidewise swing of the car was sufficient to cause a slight deflection on each side of the zero and hence the slight irregularities on the chart.

In looking at the calibration curve it is at once evident that there are not enough points from which to draw a good curve. This was due mainly to lack of time in running sufficient tests from which to calculate the points. The points being off of the

calibration curve is probably accounted for in the imperfections of the instrument. The main difficulty in the instrument was in holding the high tension current to the proper path and preventing it from leaking across from point to point in the scales.

CONCLUSION.

With the rebuilding of the scale of the instrument and the proper balancing of the needle it is thought that no difficulty will be encountered in obtaining a calibration curve on which all the points will lie.

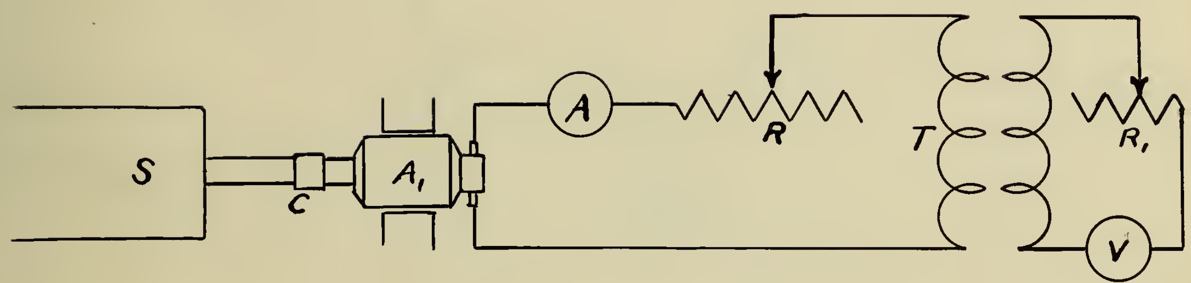


Fig. 1.

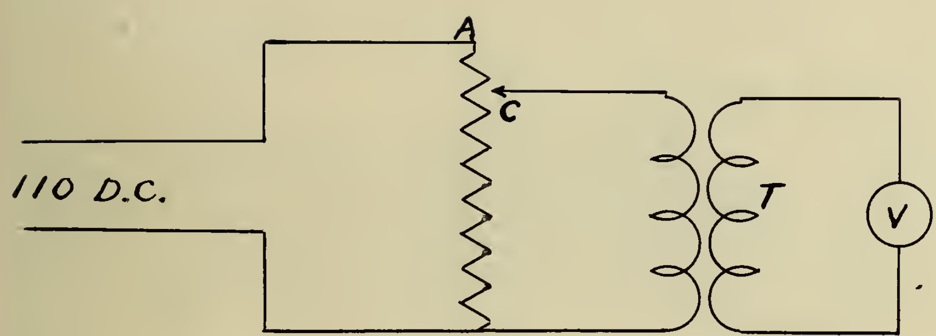


Fig. 2.

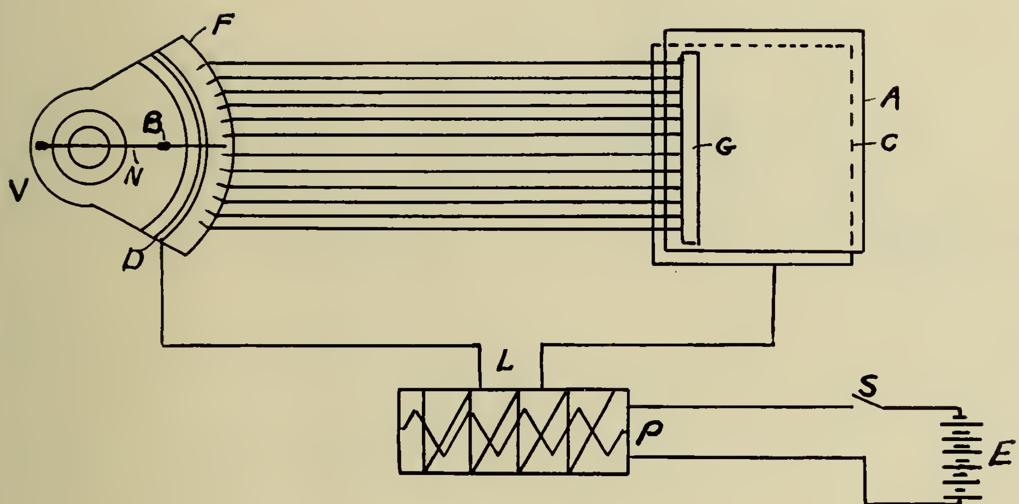


Fig. 3.

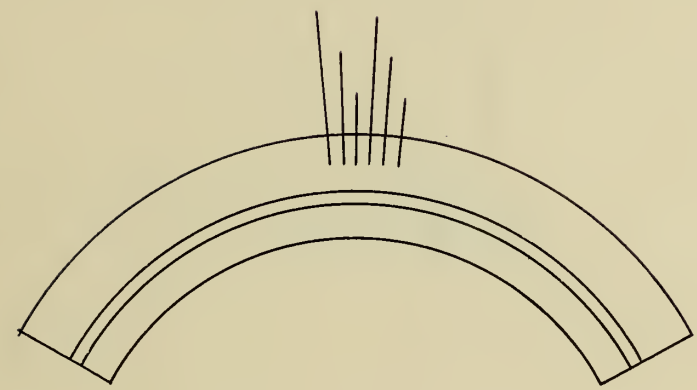


Fig. 4.

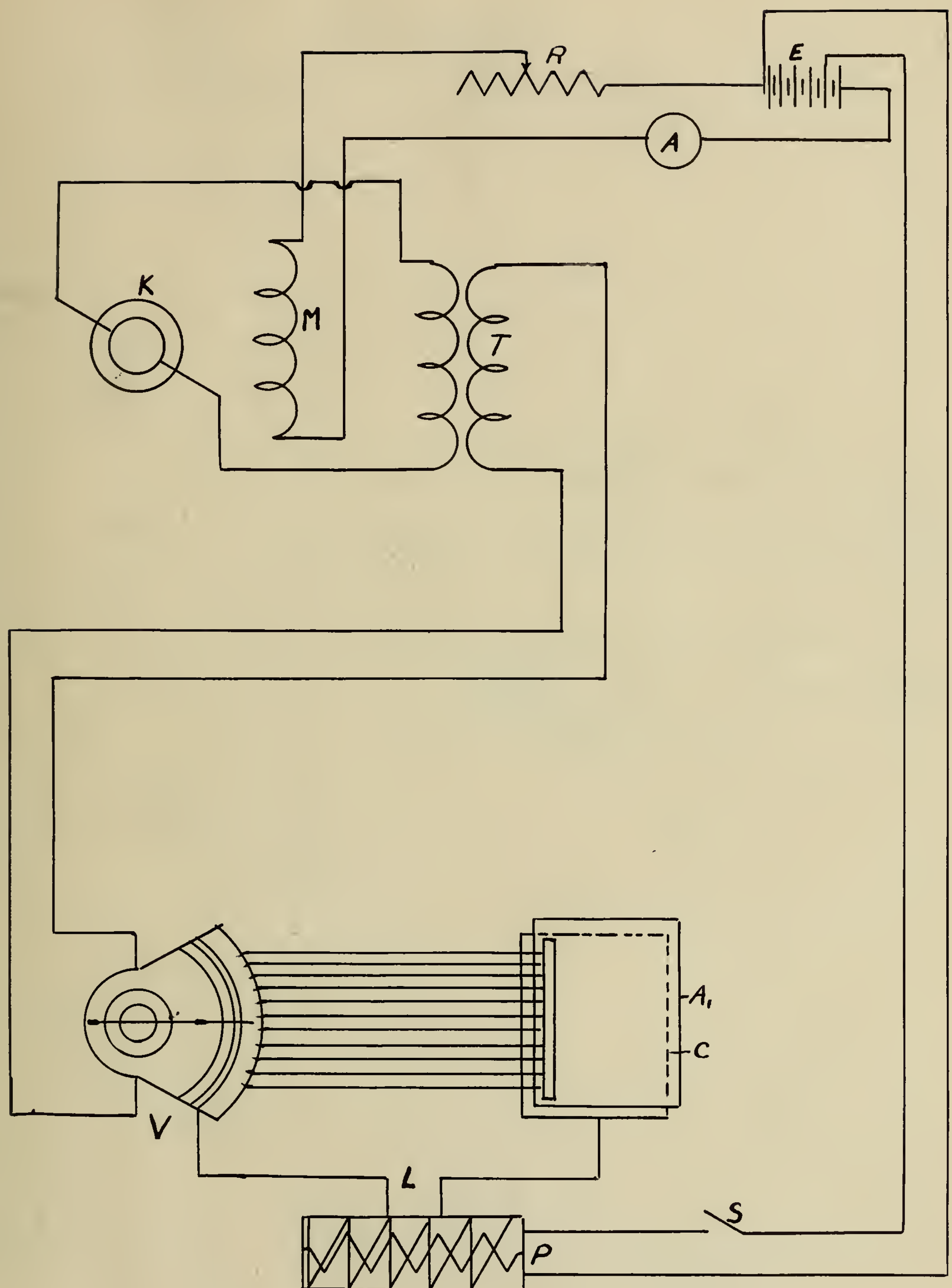


Fig. 5.

FIG. 6.

A– SPEED CURVE FROM CHART.

B – ACCELEROMETER CURVE FROM CHART

C – ACCELEROMETER CURVE CALCULATED.

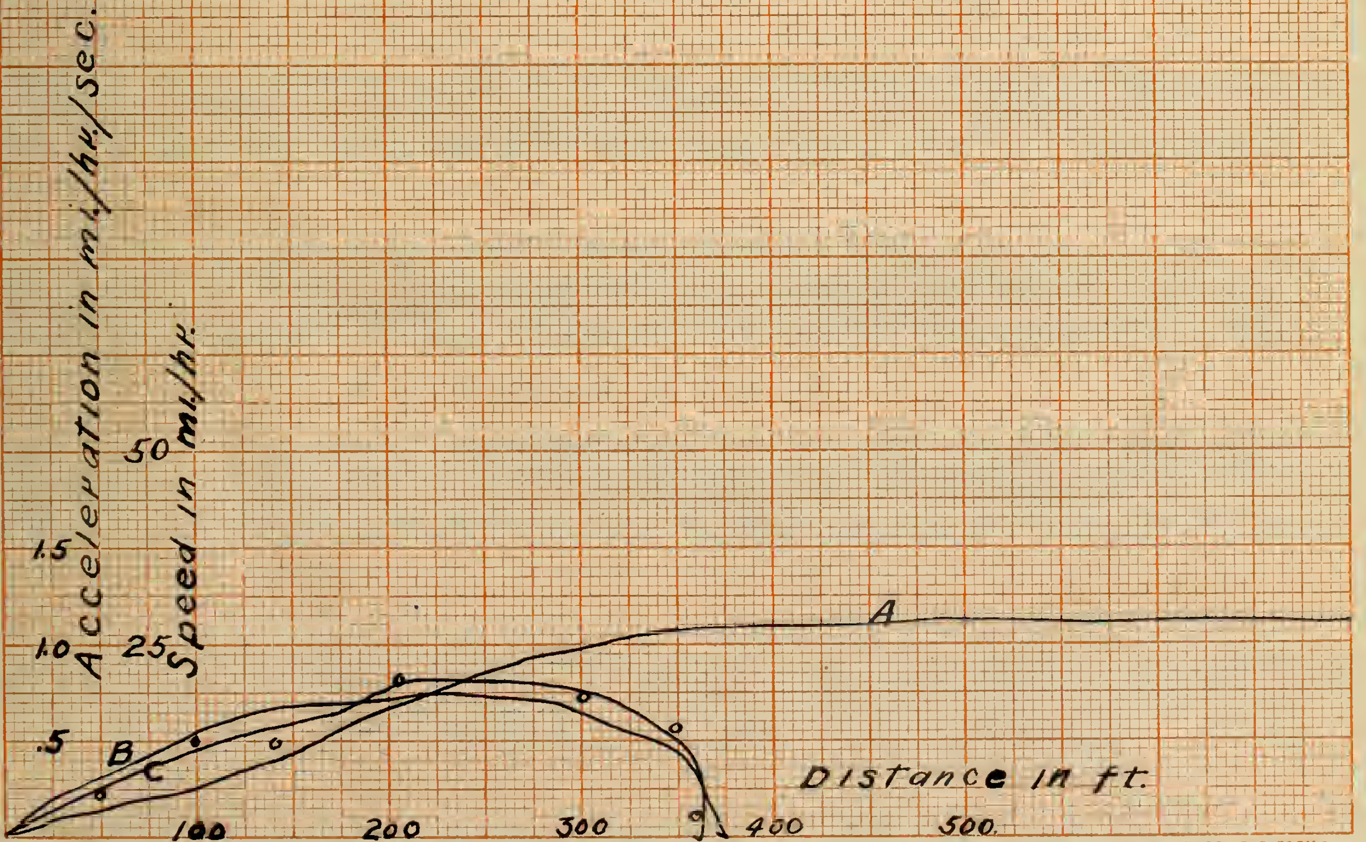
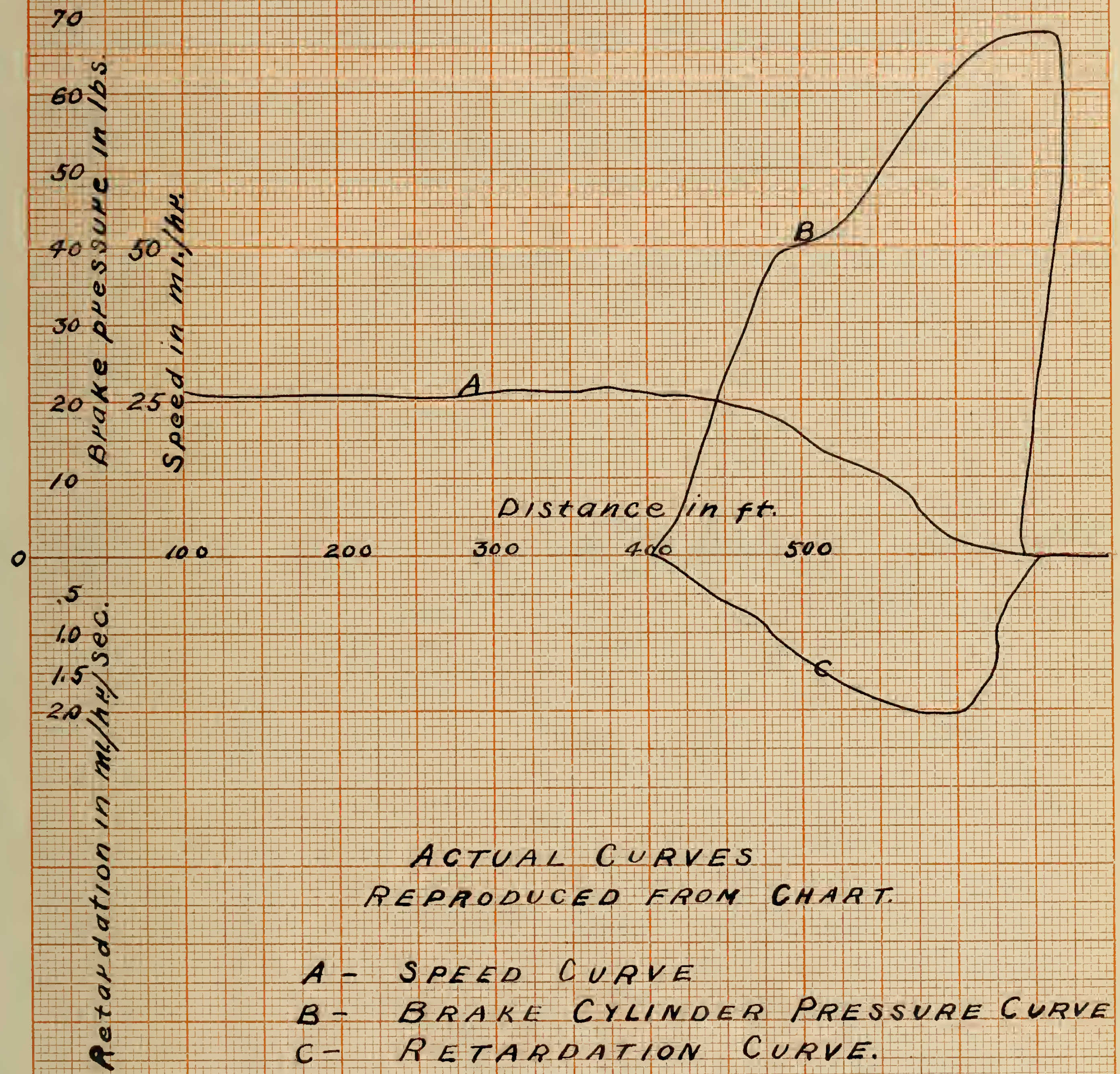


Fig. 7.



ACTUAL CURVES
REPRODUCED FROM CHART.

A – SPEED CURVE
B – BRAKE CYLINDER PRESSURE CURVE
C – RETARDATION CURVE.

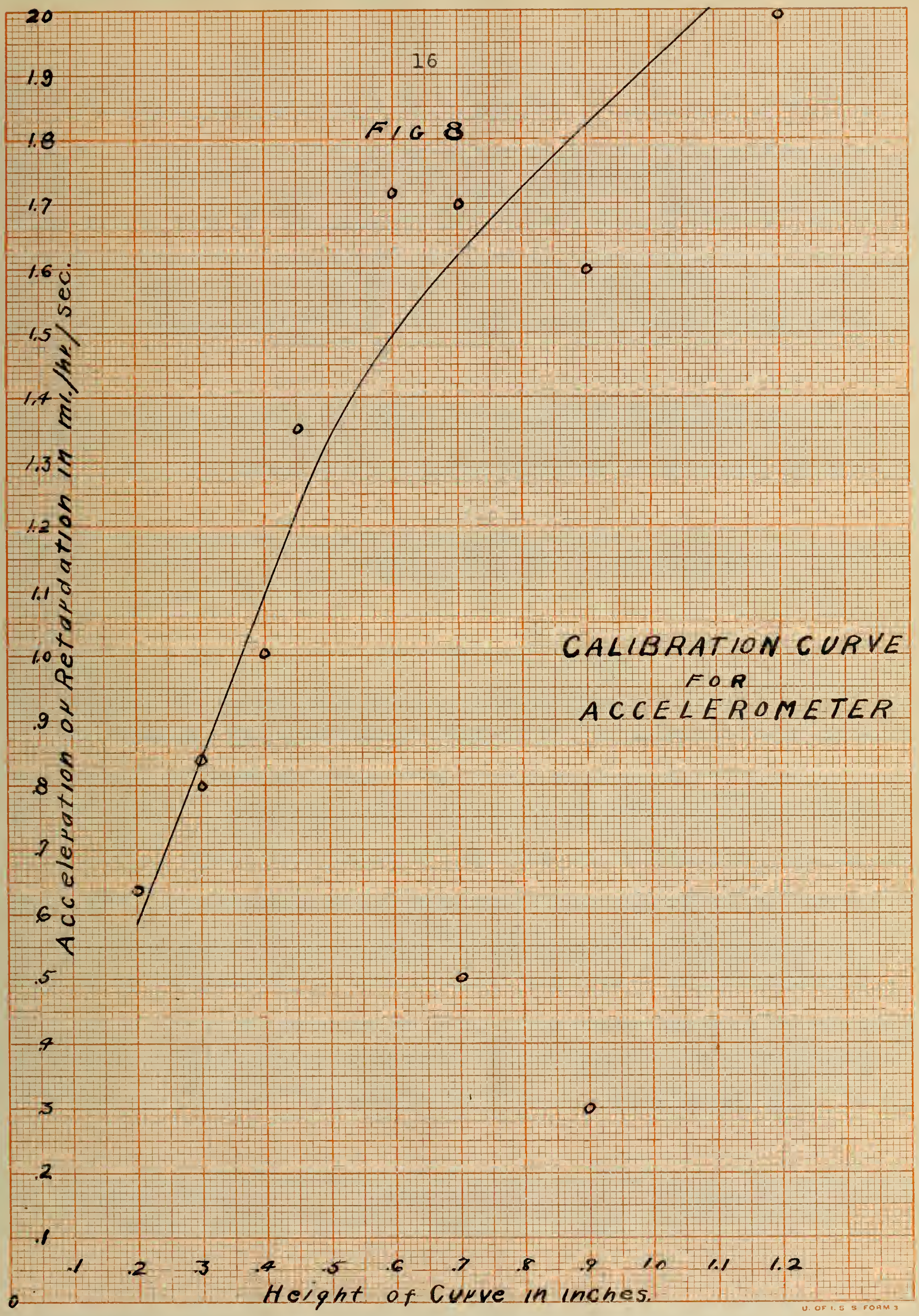
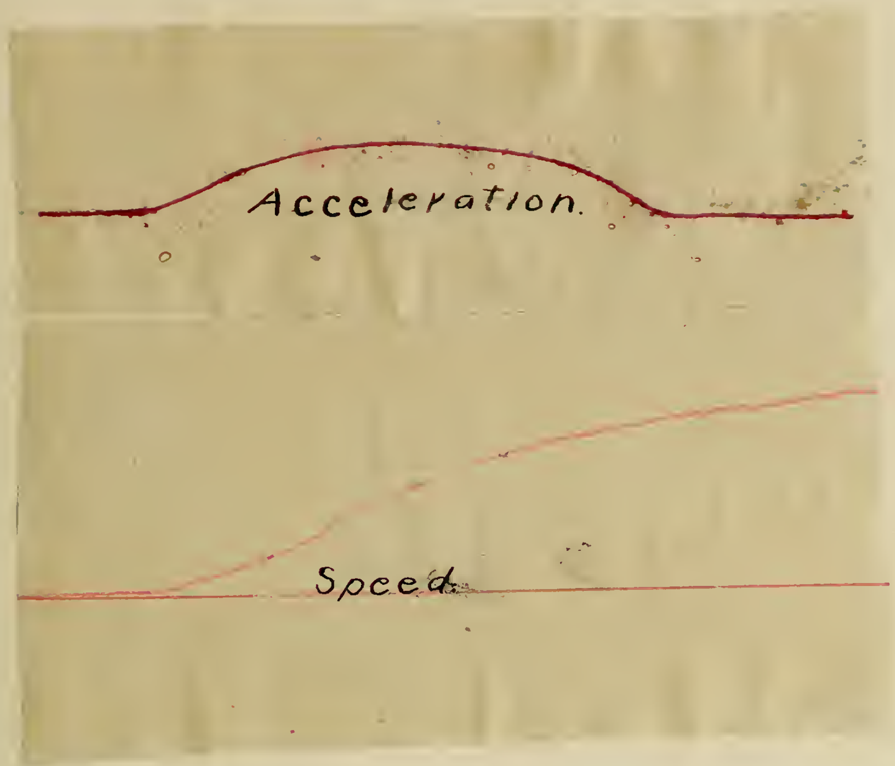


FIG 8
CALIBRATION CURVE
FOR
ACCELEROMETER
Acceleration or Retardation in mi./hr./sec.
Height of Curve in inches.
20
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
U. OF I. S. S. FORM 3



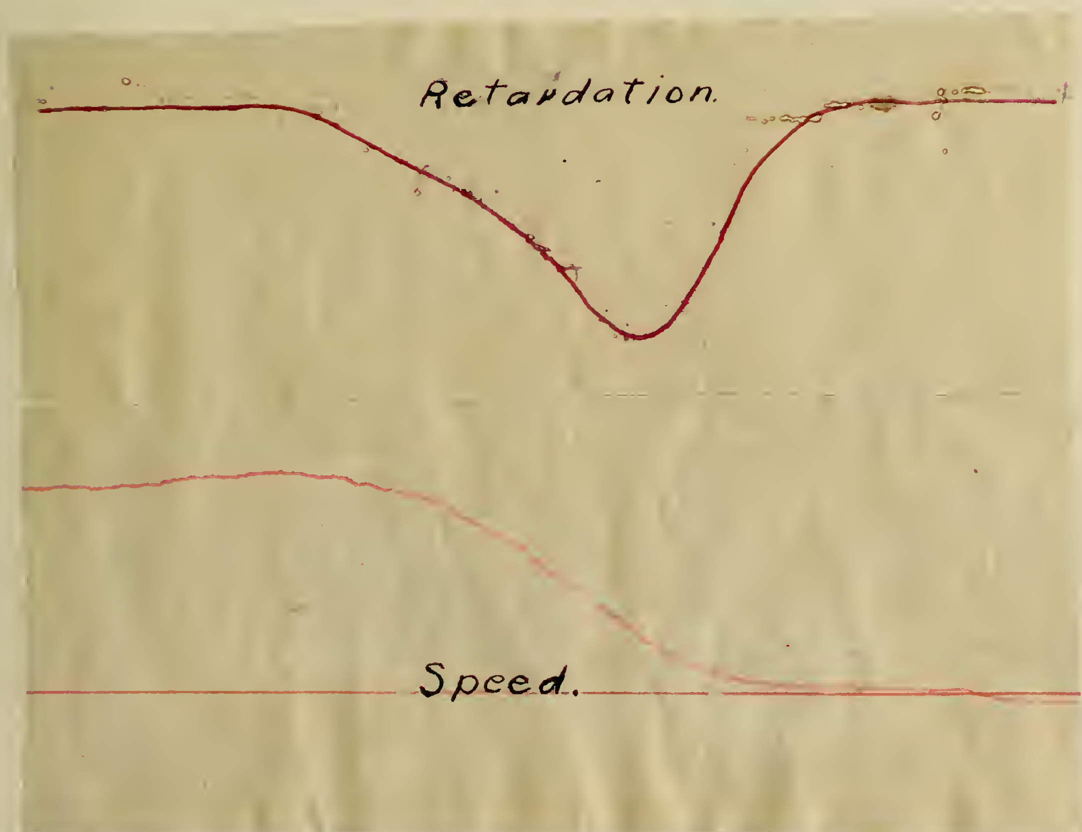


Fig 9.